Is there a 'step change' in the capital costs of coal plants?

Background

In the determination of the 2009/2010 BRCI there was a strong debate as to whether or not there had been a 'step change' in the capital costs of building power plants in Australia. In both their 2008 and 2009 reports on capital and fuel costs in the NEM, ACIL Tasman contested that there had been a recent step change upwards in the costs of building coal and gas plants. They hypothesised that this 'step change' was due to the rapid increase in commodity costs over the previous few years along with an increase demand for generating equipment worldwide. This hypothesis was rejected by the QCA who claimed that there was not enough evidence to support this view.

Before the 2009/2010 BRCI final report was released in June 2009, the QCA hired Concept Economics to assess whether there had been a 'step change' in the cost of building power plants in the NEM. In order to assess this, Concept Economics extracted data from ACIL's charts of capital build costs for coal and CCGT plants in Australia and then statistically tested for a 'structural break' in both series.

Concept concluded that there was evidence of a 'structural break' in the CCGT series but rejected the hypothesis that there was a structural break in the coal plant series. This report reviews Concept's assessment that there is no 'structural break' in the coal series.

Section 1: Replication of Concept's regression results for coal capital costs

Data has been extracted from Figure 3 of Concept's report "Review of inputs to costs modelling of the NEM." The data for this figure was itself extracted by Concept from a chart in ACIL Tasman's report. This data is listed in Appendix 1 and while it may no be the exact number's used by Concept or ACIL, they (the numbers) are close enough for replication and comparison purposes.

Concept took the natural logarithm of the nominal cost series in order to remove the effect of compounding and then used an Ordinary Least Squares (OLS) regression to fit two trend lines to the series with a structural break occurring at 2005. We have reproduced the results of this regression below and also included Concept's numbers for comparison, the chart below also plots this fit to the logarithm series. The raw data used for this regression is listed in Appendix 2 so that it can be reproduced.

Concept Regression Numbers[1]

	Coefficients	Standard error	P-value
Constant	7.1878	0.0906	0.0000
Year	0.0047	0.0173	0.7872
Step	0.1734	0.2052	0.4106
Slope	0.0897	0.0671	0.1996
Adjusted R-squared	0.588		

Replicated Regression Numbers[2]

	Coefficients	Standard error	P-value
Constant	7.1933	0.0770	0.0000
Year	0.0045	0.0173	0.7998
Step	-0.8167	0.8596	0.3562
Slope	0.0901	0.0673	0.1996
Adjusted R-squared	0.585		

We note that all our numbers are very similar to Concept's except for the coefficient of the 'Step' parameter which we believe is due to a different parameterisation of the model. It looks like Concept's 'Step' parameter (0.17) equals 1 plus our parameter (-0.82). Regardless of the parameterisation of the model, the results of statistical tests will be the same.

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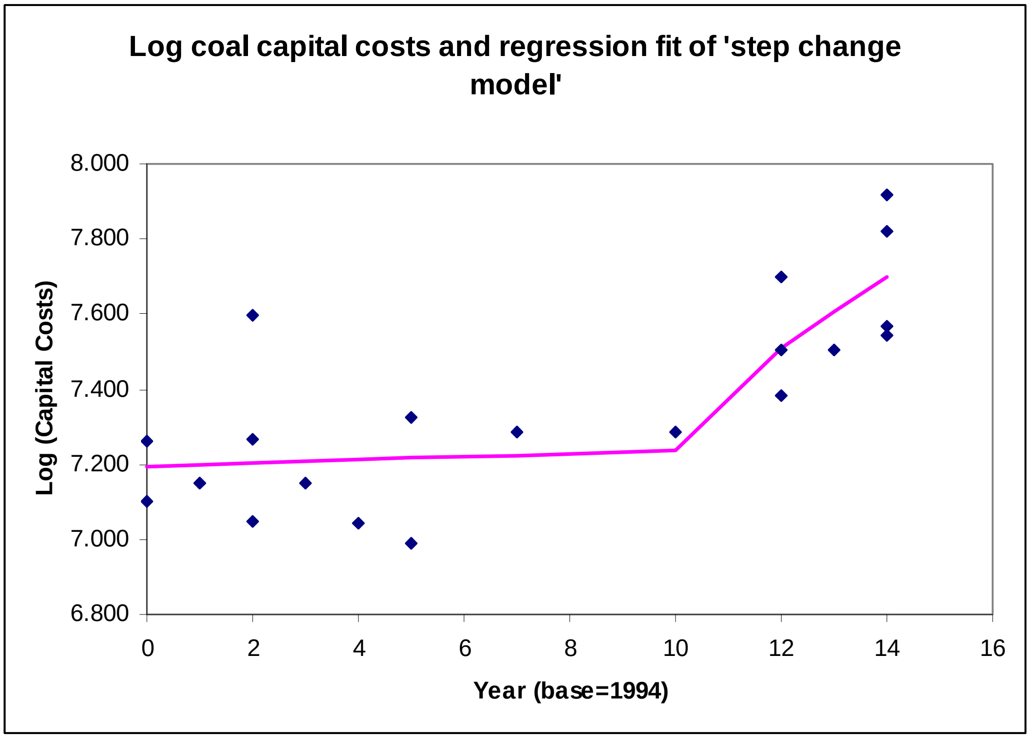
[1] From page 51 of Concept's report

[2] Based on extracted data (see Appendix 1 and 2)



Section 2: Replication of Concept's F-test of a step change

Concept tested the hypothesis of a step change by performing an 'F' or 'Wald' test on the join restriction that the Step and Slope parameters are jointly insignificant. If both of these parameters are jointly insignificant then the hypothesis of 'no step change' can confidently be rejected. Technically their null hypothesis is:
'Slope' coefficient = 0 AND 'Step' coefficient = 0

Below we have reproduced the results of this test and included concept's numbers for comparison.

Concept F-test result

F-value	Unknown
P-Value	0.1273

Replicated result

F-value	2.3521
P-Value (F(2,16))	0.1272

Again we have reproduced Concept's numbers to within numerical error.

Section 3: Correction of the F-test

One of the main assumptions of the Wald test is that the error term in the regression is conditionally homoskedastic (i.e. the residuals in the regression do not depend on any of the regressors or change over time). Concept in their report note indirectly that the residuals appear heteroskedastic when they state "the estimated costs of CCGT capital projects is much tighter in 2006, 2007 and 2008 then in previous years" and that "the non-constant variance can affect the efficiency of statistical tests" but then make no attempt to correct for it.

Below is the result of the Wald test when the change in the variance of the error term is corrected for by using robust standard errors (White 1980) rather than the classical variance estimator. Details of the test can be found in Appendix 3. Now we find that the structural break is highly significant with a p-value of less than 1% indicating that there has indeed been a structural break in the capital cost of coal plant.

Wald test result using robust standard errors

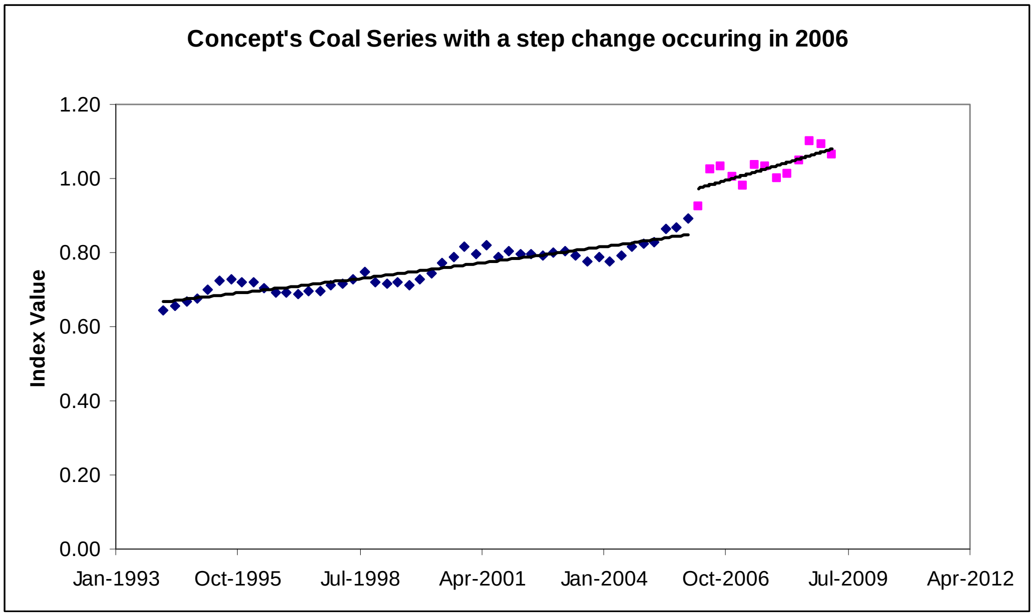
F-value	10.982
P-Value (χ^2 (2))	0.004

Section 4: Is there a structural break in Concept's index series for Black coal capital costs?

In their report, Concept construct a new index of capital costs in the NEM using ABS data rather than replying on ACIL's data. In this section we test if there is a structural break in Concept's Black Coal series at the same time as it was found in the ACIL data (2006 onwards).

Concept's Black Coal index

Concept's Black Coal index was reconstructed from information in their report and Australian Bureau of Statistics data.



Regression results for a structural break in Concept's series

Similar to the method in Section 1 of this report, the log of the index series was taken and then a regression performed with a structural break occurring at the beginning of 2006. The results of this regression are below:

	Coefficients	Robust standard error	P-value
Constant	-0.4091	0.0093	0.0000
Year	0.0203	0.0013	0.0000
Step	-0.0399	0.1493	0.7900
Slope	0.0142	0.0106	0.1880
Adjusted R-squared	0.9554		

Wald test of a structural break using robust standard errors

Using the same method as in Section 3 we test if the structural break in Concept's coal series is significant. We find that the structural break is highly significant with a p-value of less than 1% indicating that there has indeed been a structural break in the capital cost of coal plant.

F-value	57.80
P-Value (χ^2 (2))	0.000

Conclusion

We have found that there is indeed a structural break in both ACIL's and Concept's capital cost series for coal plants. Given how similar Concept's Black Coal, Brown Coal, CCGT and OCGT series are we believe that we would also find a structural break in these series but have not tested for this.

References

- White, Halbert (1980) A heteroskedasticity-consistent covariance matrix and a direct test for heteroskedasticity, *Econometrica* 48, 817–838

Appendix 1: Data obtained from Figure 3 of Concept's report

Year	Coal plant nominal cost
1994	$ 1,215.26
1994	$ 1,426.61
1995	$ 1,273.97
1996	$ 1,150.68
1996	$ 1,996.09
1996	$ 1,432.49
1997	$ 1,273.97
1998	$ 1,144.81
1999	$ 1,514.68
1999	$ 1,086.11
2001	$ 1,455.97
2004	$ 1,455.97
2006	$ 1,608.61
2006	$ 2,201.57
2006	$ 1,814.09
2007	$ 1,819.96
2008	$ 1,884.54
2008	$ 1,937.38
2008	$ 2,495.11
2008	$ 2,747.55

Appendix 2: Data used in regression

Please note that it appears that Concept has rebased the Year series so that the base year is 1994 (i.e 1994 = year 0).

X =

Intercept	Year	Step	Slope
1	0	0	0
1	0	0	0
1	1	0	0
1	2	0	0
1	2	0	0
1	2	0	0
1	3	0	0
1	4	0	0
1	5	0	0
1	5	0	0
1	7	0	0
1	10	1	0
1	12	1	12
1	12	1	12
1	12	1	12
1	13	1	13
1	14	1	14
1	14	1	14
1	14	1	14
1	14	1	14

Y=

ln(Nominal Coal Capital Cost)
7.103
7.263
7.150
7.048
7.599
7.267
7.150
7.043
7.323
6.990
7.283
7.283
7.383
7.697
7.503
7.507
7.541
7.569
7.822
7.918

Appendix 3: Correcting for conditional heteroskedasticity

The most common way to correct for conditional heteroskedasticity in regression models is to use "robust standard errors" which are available in nearly all statistical software packages. Look for an option called "robust standard errors," "heteroskedasticity-consistent standard errors" or "Whites standard errors." If this option is not available then you can use the following formula to calculate them. For more information consult a statistical or econometrics theory book.

Method

Let the regression model in standard matrix notation be:

$$\underset{(n\times 1)}{\mathbf{Y}} = \underset{(n\times k)}{\mathbf{X}} \underset{(k\times)1}{\boldsymbol{\beta}} + \underset{(n\times 1)}{\varepsilon}$$

In order to test the joint significance of two or more regressors, linear restrictions are placed on the model which we note as:

$$H_0 : \underset{(\#r\times k)}{\mathbf{R}} \underset{(k\times 1)}{\boldsymbol{\beta}} = \underset{(\#r\times 1)}{\mathbf{r}}$$

In Section 3, we are testing if the Step and Slope coefficients are jointly insignificant, and so #r = 2, and **R** and **r** are given by

$$\underset{(2\times 4)}{\mathbf{R}} = \begin{bmatrix} 0\,0\,1\,0 \\ 0\,0\,0\,1 \end{bmatrix}, \quad \text{and} \quad \underset{(2\times 1)}{\mathbf{r}} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

The formula for the F test is:

$$F = n \bullet (\mathbf{Rb} - \mathbf{r})' \left\{\mathbf{R}\left[\overline{\text{Avar}(\mathbf{b})}\right]\mathbf{R}'\right\}^{-1} (\mathbf{Rb} - \mathbf{r})/\#r$$

where $\overline{\text{Avar}(\mathbf{b})}$ is a consistent estimator of the asymptotic covariance matrix of the parameter vector **b**. The F test is distributed F(#r,n-K).

In the classical case where the residual are homoskedastic, the estimator of the covariance matrix is calculated as

$$\overline{\text{Avar}(\mathbf{b})} = n\, s^2 \, (\mathbf{X}'\mathbf{X})^{-1}$$

In the case of conditional heteroskedasticity, the estimate of the asymptotic variance of **b** ($\overline{\text{Avar}(\mathbf{b})}$) is inefficient and so is replaced by an estimator that is robust in the presence of heteroskedasticity. The most common estimator is White's (1980) which is given by:

$$\overline{\text{Avar}(\mathbf{b})} = n\,(\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\mathbf{H}\mathbf{X})(\mathbf{X}'\mathbf{X})^{-1}$$

where **H** is a diagonal matrix of the estimated residuals

$$\mathbf{H} = \begin{bmatrix} \hat{\varepsilon}_1 & & \\ & \ddots & \\ & & \hat{\varepsilon}_{\mathbf{n}} \end{bmatrix}$$

The test statistic is very similar to the F test

$$W = n \bullet (\mathbf{Rb} - \mathbf{r})' \left\{\mathbf{R}\left[\overline{\text{Avar}(\mathbf{b})}\right]\mathbf{R}'\right\}^{-1} (\mathbf{Rb} - \mathbf{r})$$

But it is distributed $\chi^2(\#r)$.